ENGINEERING EDUCATION PLANS

Continuing Efforts:
- Engineering Education Research;
- Engineering Education Program;
- Nanotechnology Undergraduate Education (NUE);
- International Research and Education in Engineering (IREE); and
- Fall 2007 Education Grantee Meeting

New Initiatives:
- Council of Associate Deans for Undergraduate Programs
- The Business of Engineering Education
- Workshop on Renaissance in Engineering Ph.D. Education.

Continuing Efforts

Engineering Education Research

Throughout the 1980s and 1990s, there was a major push by NSF through the Engineering Coalitions Program to reform and modernize engineering education, and then institutionalize the changes.

This program met with moderate success and offered many lessons. Probably the program's most significant changes occurred in two areas:.first, there was widespread reform of the first-year experience in engineering programs to increase retention. An outgrowth of this effort was the Department Level Reform Solicitation, which was focused on Undergraduate Engineering Education Reform. This program was directed at departmental or larger units looking to transform their programs or develop new curricula in order to meet the nation's need for a vibrant engineering workforce. Funding was available as either a one-year planning grant for $100,000 or as an implementation grant for up to $1 million. The project's annual allocation was $4.5 million before the program was terminated in fiscal year 2005.

Second, engineering education research was established as an area of scholarly pursuit for engineering faculty (examples include the Vanderbilt, Northwestern, Harvard/MIT, Texas (VaNHT) ERC, National Academy of Engineering (NAE) Center for the Advancement of Scholarship in Engineering Education (CASEE), and ASEE's *Journal of Engineering Education*).

With the establishment of engineering education as a research area, Engineering Education at NSF has supported the formation of a national research agenda and a shift from an unsolicited proposal approach to a more focused one. Fundamental research is needed to define the fundamental knowledge and skills that engineers should possess, how they can best learn these skills, and how the engineering curriculum can be structured to make efficient and effective use of university and faculty resources. EEC has established the Engineering Education Program to effect this more focused approach.

Engineering Education Program

The two main objectives of the Engineering Education Program are: (1) to support research that contributes to a basic understanding of how students learn engineering and (2) to attract talented students, especially women and underrepresented minorities, to all levels of engineering education.

The program funded seven awards in its first year, fiscal year 2006, and 10 awards in fiscal year 2007.

It is expected that projects will be supported that contribute to significant breakthroughs in understanding so that our undergraduate and graduate engineering education can be transformed to meet the needs of the changing economy and society. Specifically, we are interested in research that addresses the following areas, briefly described as:

- **Area 1—Engineering Epistemologies:** Research on what constitutes engineering thinking and knowledge within social contexts now and into the future.
- **Area 2—Engineering Learning Mechanisms:** Research on engineering learners' developing knowledge and competencies in context.
- **Area 3—Engineering Learning Systems:** Research on instructional culture and institutional infrastructure, and on the knowledge of engineering educators.
- **Area 4—Engineering Diversity and Inclusiveness:** Research on how diverse human talents contribute solutions to social and global challenges and thus to the relevance of the engineering profession.
- **Area 5—Engineering Assessment:** Research on, and the development of, assessment methods, instruments and metrics to inform engineering education practice and to inform learning.

Additional areas that are being considered are Entrepreneurial Education, e-Learning, and Capstone Design:

Entrepreneurial Education

The American *Competitiveness Initiative* states that "sustained scientific advancement and innovation are key to maintaining our competitive edge." Additionally, the NAE report *Engineer of 2020* indicates that students will need to be educated as innovators, with more direct exposure to cross-disciplinary topics and the workings of an entrepreneurial economy.

As more colleges and universities seek to incorporate innovation and entrepreneurial activities into their curricula, researchers will need to study and address new issues. They will need to assess entrepreneurial programs to gauge how they assist and prepare students to work in entrepreneurial environments; how they facilitate learning of concepts related to entrepreneurship; what role entrepreneurial programs play in helping students learn how to incorporate innovation into product and service design and commercialization; and how they help students learn entrepreneurial skills. Researchers will also need to understand what constitutes entrepreneurial skills; how well students understand the innovation process; and what the concepts of entrepreneurship are.

Some of the leading entities in this area are the Kauffman Foundation, the National Collegiate Inventors and Innovators Alliance, and the Lemelson Foundation.

Web-based Education e-Learning

E-learning continues to grow within higher education. Resources and research to help educators develop practices in this area are greatly needed. E-learning describes issues related to online learning, Web-based training and technology-delivered instruction. Critical to the advancement of e-learning is the ability to offer information supporting student learning through the use of information and communication technologies. Issues of interest might include: the use of network technologies to create, foster, deliver and facilitate learning, anytime and anywhere; and the delivery of individualized, comprehensive, dynamic learning content in real time, aiding the development of communities of knowledge and linking learners and practitioners with experts.

Capstone Design

All programs accredited by ABET, Inc. (previously the Accreditation Board for Engineering and Technology) require a capstone design experience, often a sequence of courses. Faculty members seek projects, often from external sources, that challenge students to apply their knowledge from a wide spectrum of their curriculum. The primary objective is to encourage innovation in product and process design, often in a team setting. For many engineering students, the experience is the first opportunity to work with a client on an open-ended problem. Many agree that the capstone experience is the single most important component of the engineering student's education.

Nanotechnology Undergraduate Education (NUE)

The Nanotechnology Undergraduate Education (NUE) program, initiated in fiscal year 2003 as a component of the NSF Nanoscale Science and Engineering (NSE) program, provides grants that enable individuals, departments, programs or campuses to integrate nanoscale science and engineering into their curricula. It includes the Nanoscale Interdisciplinary Research Teams (NIRT), the Nanoscale Exploratory Research (NER), and the Nanoscale Science and Engineering Centers (NSEC) programs.

In its first two years, fiscal years 2003 and 2004, the NUE program was managed by the Division of Chemistry in the Directorate for Mathematical and Physical Sciences (MPS), with co-funding provided by ENG. MPS participation stopped in fiscal year 2005. The EEC assumed management of the program with co-funding from the Directorate of

Education and Human Resources (EHR) and the Directorate of Social, Behavioral and Economic Sciences (SBE).

The NUE program emphasizes new approaches to undergraduate engineering education through interdisciplinary collaborations. These collaborations could lead to, but are not limited to:

- New examples of undergraduate nanoscale engineering courses that are presented through the development of laboratory and demonstration experiments, manuals and other written materials, software, and Web-based resources;
- Development and dissemination of new teaching modules for nanoscale engineering of relevance to engineering education that can be used in existing undergraduate courses.

Award amounts in the first two years of the program were $100,000. In fiscal year 2003, 33 awards were funded for a total of $3.3 million and in fiscal year 2004, 34 awards were funded for a total of $3.3 million. Beginning in fiscal year 2005, the award amount was increased to $200,000 for a period of 24 months. The total number of awards funded in fiscal year 2005 was 14 for a total of $2.7 million and, in fiscal year 2006, 11 for a total of $2.1 million.

The NUE program, now in its fifth year, involves three NSF directorates for fiscal year 2007: ENG, SBE and EHR. The fiscal year 2007 program solicitation is focused on nanoscale engineering education with relevance to devices and systems. Another focus is on ethical, legal, economic and other social implications of nanotechnology. The total budget available for fiscal year 2007 is $1.9 million; it is estimated that 10 awards will be funded.

International Research and Education in Engineering (IREE) Program

The IREE program provides supplements to existing awards supported by ENG divisions to enable early-career researchers in the United States to gain international research experience and perspective. Additionally, by broadening existing research projects funded by ENG programs through partnership with self-supported foreign counterparts, IREE seeks to enhance U.S. innovation in both research and education. Early-career researchers include undergraduate and graduate students, postdoctoral fellows, and early-career faculty members.

Initiated in 2006, IREE funds medium-duration (three to six months) visits by U.S. early-career researchers to collaborating institutions and laboratories outside of the United States. The visits must be related to the objectives of ongoing work in current projects, augmented by evidence of engagement with the cultural activities in the countries visited.

Because of its connection with both the Engineering Education and the Human Resources programs of EEC, and because it focuses on developing the potential of early-career researchers, IREE is also linked to EEC’s leadership role in integrating research with education. Thus, the principal mission of IREE enables the connection of the research programs of ENG divisions with the education of students.

The IREE partnerships together create an important bridge between EEC and other ENG divisions and between EEC and the Office of International Science and Engineering (OISE). In 2006, this bridge linked EEC to more than 100 awards in other ENG divisions. These awards represented a total estimated investment by the ENG divisions of at least $50 million.

Fall 2007 Education Grantees Meeting

In the spring of 2005, EEC, along with the Directorate for Computer and Information Science and Engineering (CISE) and EHR, hosted a grantees meeting focused on engineering and computer science education. A second meeting occurred in the fall of 2007. It is intended that EEC will annually sponsor the grantees conference focusing on research briefings, new ideas and the benchmarking of best practices.

New initiatives

Council of Associate Deans for Undergraduate Programs

There are nearly 400 accredited colleges of engineering in the United States, and most are organized alike. A dean serves as the CEO with several chief operating officers, who in academe have titles like Associate Dean of Graduate/Research Programs and Associate Dean for Undergraduate Programs. Larger schools may have additional officers focusing on administration, outreach, and the like.

Interestingly, the Associate Deans of Graduate/Research Programs have, for the last 25 years or so, organized into the Engineering Research Council under the umbrella of ASEE. The council hosts regular communications, annual meetings, and even an award for Outstanding Administration. It exists to promote graduate education and research in engineering and, while doing so, share best practices across all engineering colleges.

For reasons that are not altogether clear, a corresponding “Council of Associate Deans for Undergraduate Programs” in engineering has never evolved. Surely, many of the undergraduate issues that exist at different engineering schools are not unique. Engineering programs are all accredited by ABET, Inc., and professional societies, such as IEEE, ASME, and the Institute of Industrial Engineers, serve their student members uniformly across the nation. Unfortunately, no formal council of these leaders in undergraduate engineering education exists. Such a body could be a significant force in shaping, assessing, and implementing research in engineering education and in defining new needs.

Associate Deans of Undergraduate Programs have responsibility and oversight with many of the following functions:

- Assignment of instructors;
- Coordination of faculty who are teaching mathematics, chemistry and physics;
- Course evaluations by students;
- Assignment of space for rooms and laboratories;
- Orientation of new faculty for teaching effectiveness;
- Workshops for teaching assistants;
- Leadership of K–12 outreach efforts; and
- Compilation and analysis of retention statistics.

No doubt these faculty members have other responsibilities. Even more important than their duties is the fact that faculty members appointed to such leadership positions invariably have had outstanding careers of teaching and advising. As a result, they could form a powerful group for advancing the quality of and commitment to improving undergraduate engineering education.

The Business of Engineering Education

A longstanding issue about faculty career paths in academe, especially in engineering, is the balance between teaching and research. It is the common belief among engineering faculty that accomplishments and success in research are rewarded at a significantly higher level than similar success in the classroom. Certainly, success in research brings financial resources and high visibility to an engineering school and various national ratings and rankings seem to be dominated by research and scholarship of the faculty. Often a faculty member's teaching success is only of minor consequence in reaching tenure, and being satisfactory is often enough, much like a pass-fail grade.

One of the inherent difficulties in promoting the importance of quality in the classroom relates to its measurement and how this measurement relates to the business model of the college or university. Faculty classroom success or lack thereof is measured principally in one of the following ways: 1) student evaluations, 2) classroom peer assessment or 3) curricula materials.

Some schools use (require) all these processes, but the single most important is usually the student evaluations. This instrument provides an immediate and vivid view of the student's real-time assessment of the class and instructor. Some schools require that every course and every instructor in every term be evaluated by the students; but there is great variation among schools.

However, the use of student evaluations for measuring course quality is by no means universally accepted as valid. The two major criticisms of this metric are, among others, that:

- A student's evaluation is influenced by the student's expected grade, and
- Students often rate an instructor as "superior" based on the instructor's personality rather than on what they actually learned.

At the same time, a study of more than 60,000 course evaluations at one school (in 2004/2005, Northeastern University) strongly suggests that neither of these criticisms is valid. Course evaluations for all courses (freshman through seniors) at Northeastern University included 14 questions answered on a scale of 1–5, with 5 being the highest. Three of the questions were:

1. Overall teacher effectiveness
2. Amount learned
3. Expected grade (F-1,D-2 … A-5)

Linear regression was determined for answers given for (1) and (2) and then for answers given for (1) and (3), and the correlation coefficient for each comparison showed a clear trend. The correlation coefficient between (1) and (2) was positive (0.85), suggesting a strong relationship between a student's perception of teacher effectiveness and the amount the student feels she learned. The correlation coefficient between (1) and (3) was almost zero (-0.3), suggesting no relationship between a student's perception of teacher effectiveness and the grade he expects to receive.

Could these results be replicated across all U.S. engineering schools, which differ in size, location, mission (public vs. private), etc.? This question remains to be answered, but the Northeastern University data certainly suggest that teaching effectiveness and the desired outcome of knowledge transfer are highly and positively correlated. Importantly, this result underscores the intrinsic value of "quality teaching" to the college and the critical role of the engineering educator. But does it then automatically elevate the importance of teaching relative to research? Without any further insight, probably not!

What is missing are clear links between teaching effectiveness and retention/graduation and, ultimately, revenue. Clearly there must be some relationship as evidenced in the Seymour and Hewitt 1997 study, *Talking About Leaving: Why Undergraduates Leave the Sciences*. Shockingly, 98 percent of the students who left the sciences cited poor teaching by science, mathematics, engineering, and technology faculty as a reason to leave engineering. In a comprehensive study by Adelman (1998), *Women and Men of the Engineering Path: A Model for Analysis of Undergraduate Careers*, slightly more than 56 percent of all students who began pursuing a B.S. in engineering completed an engineering degree by age 30. Today, various estimates place the engineering graduation rate in the low 60 percent range. Obviously, retention and throughput in our engineering schools remain a critical problem.

When a faculty member receives a research grant the impact and, importantly, the revenue are immediately measurable, particularly its impact on the bottom line of the college budget. When a faculty member delivers a sterling course to 100 students, the impact on the bottom line is certainly not as immediate and, even more importantly, it is difficult to measure. What engineering colleges (or universities as a whole) lack is an understanding of how quality in their classrooms impacts their revenue streams.

EEC intends to support a program entitled "The Business of Engineering Education." This program will assess the impacts and benefits of engineering education from a business standpoint. The overall question is: To what degree does quality in the classroom impact the bottom line of the college and university?

Workshop on Renaissance in Engineering Ph.D. Education

The number of doctorates in engineering granted to U.S. citizens and permanent residents has fallen to little over 40 percent of the overall output (a total of 2,838 doctorates to U.S. and permanent residents compared to 3,766 foreign nationals in 2004). Furthermore, only about 3 percent of the doctorates in engineering are being granted to African American, Hispanic and Native American students. We are obviously in a crisis in the area of overall representation and diversity within this pipeline. What is happening and why?

The NAE report *The Engineer of 2020* emphasizes that increasing technological complexity, and an increasingly global business climate, demand that engineers possess a variety of skills. Three of those skills, aside from technical expertise, are communication skills, business and management acumen, and traits of good leadership. Added to this list should be the ability to be strong teachers so that many generations of engineers can meet the NAE requirements.

However, despite the clear need for a new kind of engineer, a Ph.D. in engineering still represents deep understanding of one technical area. Doctoral students gain experience in research methods and learn to communicate research results, although these skills vary greatly. Some Ph.D. candidates gain teaching experience, for example as teaching assistants, but many do not.

Clearly, all the ENG divisions have a principal responsibility for ensuring that university Ph.D. programs not only remain strong and vibrant and continue to attract the most talented students, but also that they are training students to become both researchers and educators.

Additionally, the stark lack of diversity in Ph.D. programs does not bode well for the future. Some serious questions need to be addressed by the constituencies involved in U.S. engineering Ph.D. programs, including:

- Are our Ph.D. programs too narrow and specialized?
- Are our Ph.D. programs too lengthy?
- Are our Ph.D. programs too insulated?

We will host a Workshop on Renaissance in Engineering Ph.D. Education in the summer/fall of 2007 with representatives from academe, industry, government, and NSF to address these critical pedagogical issues.